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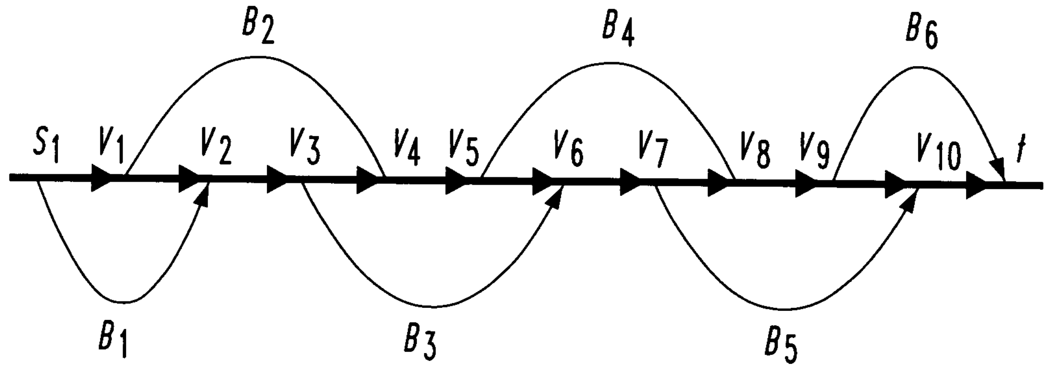

FIG. 1

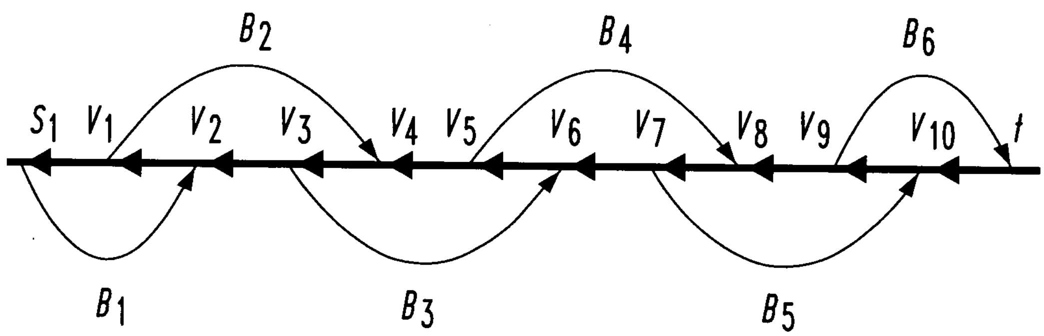

FIG. 2

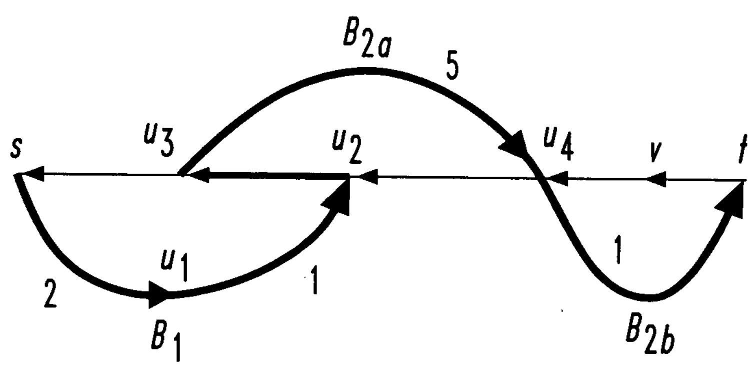

FIG. 3

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FIG. 4

Algorithm PP ($G(V,E), \hat{\mathcal{P}}, \hat{d}, U$)

parameters:

$G(V,E)$ - network,
$\{d_l, c_l\}_{l \in E}$ - delays and costs of the network links,
$\hat{\mathcal{P}} = \{s = v_0, v_1, ..., t = v_n\}$ - QoS path,
$\hat{d}$- delay constraint,
U- the upper bound on the cost of $\mathcal{R}$.

$\Delta \leftarrow \hat{d} - D(\hat{\mathcal{P}})$
$E' \leftarrow E$
for each link $l = (v_i, v_{i+1}) \in \hat{\mathcal{P}}$ **do**
  $E' \leftarrow E' \setminus \{(v_i, v_{i+1}) \in \hat{\mathcal{P}}\}$
  $E' \leftarrow E' \cup \{(v_{i+1}, v_i) \in \hat{\mathcal{P}}\}$, $c_{(v_{i+1}, v_i)} \leftarrow 0$
for all $v_i \in V$ **do**
  $D_{v_i}[0] \leftarrow \infty$
$D_s[0] \leftarrow 0$
for $c = 1, 2, ..., U$ **do**
  for each $v_j \in V$ in order such that v_j is before $v_{j'}$ if v_j is a successor of $v_{j'}$ in $\hat{\mathcal{P}}$ **do**
    $D_{v_j}[c] \leftarrow D_{v_j}[c-1]$
    for each link $l = (v_i, v_j) \in E'$ **do**
      RELAX$(l(v_i, v_j), c, \Delta)$
  if $D_t[c] \leq D(\hat{\mathcal{P}})$ **then**
    determine walk $\mathcal{W}$ by backtracking
    return $\mathcal{W}$.
return FAIL

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FIG. 4

CONTINUED FROM SHT 2/8

Procedure RELAX $(l = (v_i, v_j), c, \Delta)$

if $v_j \in \hat{\mathcal{P}}$ **and** $v_i \in \hat{\mathcal{P}}$ **then**
  if $D_{v_i}[c] \leq D(\hat{\mathcal{P}}_{(s,v_i)})$ **then**
    $D_{v_j}[c] \leftarrow \min\{D_{v_j}[c], D(\hat{\mathcal{P}}_{(s,v_j)})\}$
else
  if $c_l \leq c$ **then**
    $D_{v_j}[c] \leftarrow \min\{D_{v_j}[c], D_{v_i}[c - c_l] + d_l)\}$
  if $v_j \in \hat{\mathcal{P}}$ **and** $D_{v_j}[c] \leq D(\hat{\mathcal{P}}_{(s,v_j)}) + \Delta$ **then**
    $D_{v_j}[c] \leftarrow \min\{D_{v_j}[c], D(\hat{\mathcal{P}}_{(s,v_j)})\}$

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FIG. 5

Algorithm RT ($G(V,E), \hat{\mathcal{P}}, \hat{d}, \varepsilon$)

parameters:

$G(V,E)$ - network

$\hat{\mathcal{P}} = \{s = v_1, v_2, ..., t = v_n\}$ - QoS path,

$\hat{d}$- delay constraint

ε- approximation ratio

$L, U \leftarrow$ BOUND$(G(V,E), \hat{\mathcal{P}}, \hat{d})$
do
  $B \leftarrow \sqrt{L \cdot U}$
  if TEST$(G(V,E), \hat{\mathcal{P}}, \hat{d}, B, \varepsilon)$ returns YES **then**
    $L \leftarrow B$
  else
    $U \leftarrow 2 \cdot B$
until $U/L \leq 8$.
$\mathcal{W} \leftarrow$ SCALE$(G(V,E), \hat{\mathcal{P}}, \hat{d}, L, U, \varepsilon)$
return the restoration topology that corresponds to $\mathcal{W}$.

Procedure SCALE$(G(V,E), \hat{\mathcal{P}}, \hat{d}, L, U, \varepsilon)$

$S \leftarrow \frac{L\varepsilon}{2N}$
for each link $l \in E$ **do**
  $c'_l \leftarrow \lfloor \frac{c_l}{S} \rfloor + 1$
$\tilde{U} \leftarrow \lfloor \frac{U}{S} \rfloor + 2N$
return PP$(G(V,E), \{d_l, c'_l\}_{l \in E}, \hat{\mathcal{P}}, \hat{d}, \tilde{U})$

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FIG. 5

CONTINUED FROM SHT 4/8

Procedure TEST$(G(V,E),\hat{\mathcal{P}},\hat{d},B)$

Apply Procedure SCALE for $(G(V,E),\hat{\mathcal{P}},\hat{d},B,B,2)$
if Algorithm SCALE returned FAIL **then**
  return NO
else
  return YES

Procedure BOUND$(G(V,E),\hat{\mathcal{P}},\hat{d})$

let $c^1 < c^2 < \cdots < c^r$ the distinct costs values of the links.
$low \leftarrow 1$; $high \leftarrow r$
while $low < high - 1$
  $j \leftarrow \lfloor (high + low)/2 \rfloor$
  $E' \leftarrow \{l \mid c_l \leq c^j\}$
  set $c_l \leftarrow 1$ for each $l \in E'$
  apply Algorithm PP on $(G'(V,E'),\hat{\mathcal{P}},\hat{d},2N)$
  if Algorithm PP returned FAIL **then**
    $high \leftarrow j$
  else
    $low \leftarrow j$
$U \leftarrow 2N \cdot c^{high}$; $L \leftarrow c^{high}$;
return L, U;

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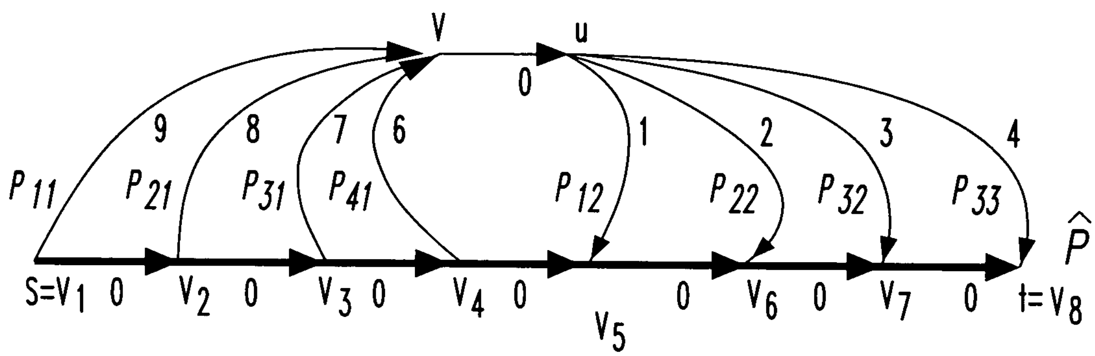

FIG. 6

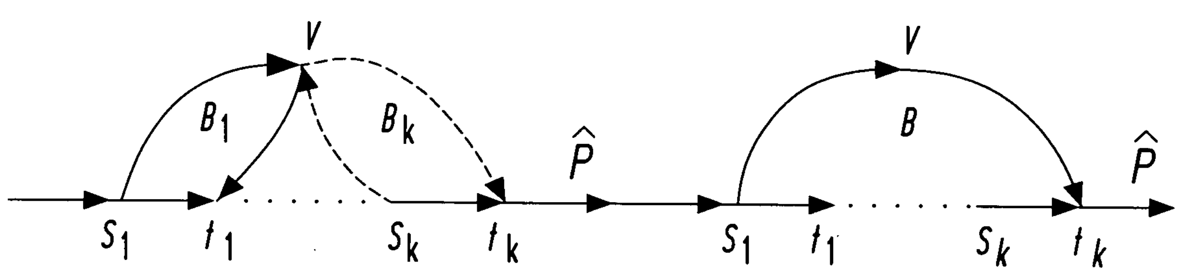

FIG. 7

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FIG. 8

Algorithm DRT ($G(V,E), \hat{\mathcal{P}}, \hat{d}, \varepsilon$)

parameters:

$G(V,E)$ - network

$\hat{\mathcal{P}} = \{s = v_1, v_2, \ldots, t = v_n\}$ - QoS path,

$\hat{d}$- delay constraint

ε- approximation ratio

$\hat{d}' \leftarrow 2\hat{d} - D(\hat{\mathcal{P}})$
$L, U \leftarrow$ BOUND$(G(V,E), \hat{\mathcal{P}}, \hat{d}')$
do
  $B \leftarrow \sqrt{L \cdot U}$
  Apply Procedure SCALE for $G(V,E), \hat{\mathcal{P}}, \hat{d}', B, B, \varepsilon)$
  if Procedure SCALE return FAIL **then**
    $L \leftarrow B$
  else
    Set $\mathcal{W}$ be the walk returned by Procedure SCALE
    if $C(\mathcal{W}) \leq L$ **then**
      return the restoration topology $\mathcal{R}$ that corresponds to $\mathcal{W}$.
    else
      $U \leftarrow 2 \cdot B$,
until $U/L \leq 8$.
Apply Procedure SCALE for $(G(V,E), \hat{\mathcal{P}}, \hat{d}', L, U, \varepsilon)$
if Procedure SCALE does not fail **then**
  Set $\mathcal{W}$ be the walk returned by Procedure SCALE
return the restoration topology $\mathcal{R}$ that corresponds to $\mathcal{W}$.

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FIG. 9

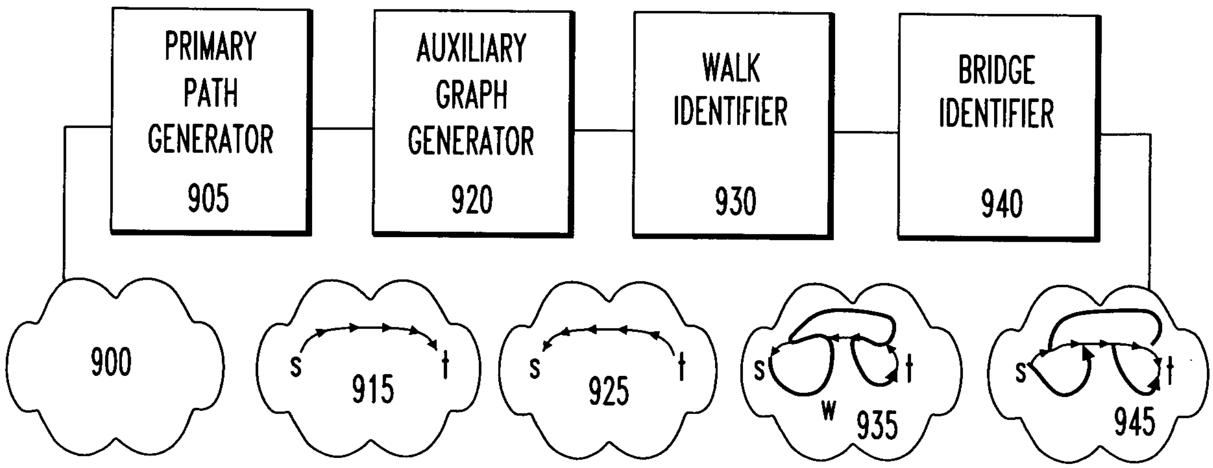

FIG. 10